Translation of "Issledovaniya Vysokochastotnogo Proboya v Gazakh v Shirokoy oblasti chastot detsimetrovogo diapazona, I" Vestnik Moskovskogo Universiteta, No. 2, 1958, pp 103-108. Author: G. A. Anashkin.

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VESTNIK

MOSKOVSKOGO UNIVERSITETA

No. 2 - 1958 p. 103-108

INVESTIGATIONS OF HIGH-FREQUENCY BREAKDOWN IN GASES OVER A WIDE RANGE OF DECIMETER WAVE FREQUENCIES - PART I

By G. A. Anashkin

In a series of works, named in references [2, 3, 6] are described experiments related to the investigation of high frequency breakdown in gases with frequencies near and over 3000 Mc in a regime of continuous uninterrupted generation.

The theory of high-frequency discharge, worked out for that very case, is established for pressures under which it is legitimate to utilize the electron diffusion in the gas representation, with an accepted breakdown criterion expressing the equilibrium of charged particles in a stabilized discharge [2].

The confrontation or theory with the obtained experimental data shows [redacted] a good concurrence. Moreover, the minimum breakdown characteristic takes place when the frequency of electrons and gas atoms collision is equal to that of the applied field.

The present work is devoted to the investigation of a high-frequency breakdown in the air, in the Argon and in the Neon over a wide range of decimeter waves under continuous generation and to the confrontation of results obtained with some available high-frequency discharge theories.

(NASA-TM-89807) INVESTIGATIONS OF HIGH-FREQUENCY BREAKDOWN IN GASES OVER A WIDE RANGE OF DECIMETER WAVE FREQUENCIES, PART 1 (NASA) 10 p

N88-70840

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METHOD OF THE EXPERIMENT

In order to investigate high-frequency breakdowns over a wide range of gas pressure and field frequencies, resonance characteristics of short-circuited co-axial line of variable length connected to the generator were utilized (Fig. 1).

Here C - the co-axial gas discharge section as a component part of a reconstructed resonance line and bounded by thin polystrene partitions hermetically sealed by application of vacuum consistent putties. G - generator. T - Thermistor capacity measurer.

Two generators of decimeter range were applied: One, operating on 85 - 30 cm. wavelength range on a metal-ceramic triode performing at a capacity of up to 22 ; the second, working on a fixed wavelength of 18.5 cm. on a triode and yielding up to 40 Watt capacity.

With the help of a piston the line was ~~turned~~ tuned each time ~~with the~~ to ~~[illegible]~~ resonance in such a way that the maximum field intensity corresponded to the center of the gas discharge section. The position and the value of the maximum was checked by means of a moving probe along the line, connected with a thermistor ~~capacity~~ power measurer T ~~[illegible]~~ carried away half-wave from the middle of the section.

It is known that ~~is~~ for a ~~maximum field~~ field maximum/ the ~~capacity~~ power is

(1)

where Z_o - wave impedance of the line in this case equal to 75 ohm. The amplitude of the high-frequency field tension in a ~~coaxial~~ co-axial resonator is written as

(2)

Where a and b ~~is~~ are inner and outer radius of the line; l — length of the resonance line; and r and Z - radial and axial three-dimensional coordinates.

The maximum amplitude of the field intensity in the inner conductor line is

(3)

Formulas (1) and (3) give:

(4)

Formula (4) may also be applied in a certain inner section of the conductor, as the electric field near the central conductor is not varying sensibly with the distance, this section being correspondingly larger for a greater wave-length.

The thermistor bridge measures that part of the ~~capacity~~ power which is branched towards the probe. xx To find the whole ~~capacity~~ power in the given point of the field it is necessary to know the probe's transitional weakening which is determined by the degree of its setting on the line of resonance. The generator's ~~capacity~~ power increase is realized by means of variation of its anode voltage.

The moment of the breakdown corresponds to a sharp deflection of the thermistor bridge indicator's arrow. Because of the existence of the statistical delay of discharge ignition, a certain spread of ~~capacity~~ power under which the breakdown occurs, has been observed.

By means of complementary ionization it was possible to obtain a vanishingly [illegible] spread

A radioactive cobalt capsule was used as such an ionizer (Co^{60} with 8.5 mc. activity placed on a lead cannon). The capsule was at a distance of 50 cm. from the gas discharge co-axial section and was irradiating it.

The section, whose inner surface was carefully cleaned and polished, was connected with the vacuum plant. Prior to carrying out the experiments, this section was worked by a high frequency discharge with an inert gas and before its filling with the gas, a vacuum of the order of 10^{-6} mm - - - was realized ~~with~~ in the plant. Air was used as an electr~~ically~~ o-negative gas, whose ~~the~~ alien admixtures such as vapor of water, ~~vapors~~ oil and putties vapors were eliminated with the help of liquid nitrogen traps. Spectrally pure Argon and Neon were selected as electropositive gases.

Experimental Results and Their Discussion

Figure 2 represents a series of breakdown characteristics taken from the electronegative gas - the air. These characteristics entail a dependence of the breakdown field intensity upon the gas pressure for different additional field frequencies. The areas of field pressure and frequencies in which lay the breakdown characteristics correspond to the transition from multiple collision of electrons with gas atoms for a single half period of change of a high frequency field to multiple half periods of change of a high frequency field.

The value of the energy (?) pickout from the field by the electrons is expressed by the known formula (1)

where $$E_e^2 = E^2 \left(\frac{\nu^2}{\nu^2 + \omega^2} \right)$$

E being the effective ~~sign~~ value of field intensity, ν - collision frequency of electrons with gas atoms; ω - circular frequency of the ~~added~~ applied field, n - number of electrons per unit of gas volume, and m and e mass and the charge of the electron. ~~with~~ With this the relation of the discharge ~~gap~~ interval dimension and the line of electrons' free path is such that it is legitimate to take advantage of the formulation of electron diffusion in the gas. The breakdown conditions in similar cases appear to be tantamount to the condition of permanency of electron concentration. In other words, the ~~xx~~ equality of electron's number "n" ~~increment~~ increases by way of ionization per second and ~~their~~ decreases by means of diffusion, but in case of ~~in~~ an electronegative gas, also by way of capture of electrons by gas molecules with a formation of negative ions during the same lapse of time. [2] That is why the course of every breakdown characteristic may be explained in the following manner.

For the area of high pressure [the right side of the breakdown characteristic $E = f(p)$] and as the pressure decreases, less intensity is required for the compensation of the electrons' decrease at the expense of the electronegative ions' formation and diffusion because, above all, and in accordance with (5) electrons ~~pick out~~ extract a greater energy from the field and the intensity of the ionization increases.

The breakdown characteristic minimum $E = f(p)$ corresponds to the greater energy transfer from the field to the electron, while, at the same time, the required field intensity for the breakdown is at a minimum. According to (5) this corresponds to the condition of the transition (i.e., $\nu = \omega$) which is experimentally confirmed in the given case.

For the area of low pressures (left side of the breakdown characteristic $E = f(p)$ the field intensity increase with the lowering of pressure corresponds to a decrease of energy acquired from the field.

The series of characteristics observed for Argon and Neon follow the same course. Figure 3 shows that for the minimum of $E = f(p)$ taken for various gases with different frequencies, the breakdown intensity, and the pressures corresponding to those minima, are linked by the same linear dependence.

The angle of incidence of the straight lines expressing this dependence for different gases is about the same.

The degree of ionization and also the energy acquired by the electron from the high-frequency field along the length of the free path, determine the external ~~aspect~~ form of the discharge which could be observed by cutting a longitudinal slot in the section and then covering it by glass with the help of a vacuum tight putty.

For lowering pressures, when the ~~line~~ extent of the electrons' free path is of the same order ~~than~~ as the gas discharge ~~gap,~~ interval, the discharge ~~completely~~ covers it completely and has in this case a relatively homogenous glow.

As the pressure increases, the discharge also covering completely the ~~gap~~ interval, ties itself up to the central conductor with a heterogenous glow and a brighter discharge within the area of greater field intensity. With the increase of field intensity the glow heterogenity became more apparent. For the calculation of the breakdown field intensity it is necessary to know the value of the ionization rate at a high frequency ζ as a function of E/p and of field frequency ω, i.e., $\zeta = \zeta(E/p, p\lambda)$

where p = gas pressure and λ = wavelength in the free space. With the help of known methods the solution of the equation expressing the breakdown conditions and the detailed calculation technique of breakdown field intensity in case of heterogenous field of a ~~coaxial~~ co-axial resonator [2], was written by confronting the breakdown characteristics taken ~~[illegible]~~ for Argon on 1620 Mc frequency with the diffusion theory within the limits of its applicability.

The ionization rate ζ was calculated on the basis of theoretical data by Kihara [4] who deduced it from ~~the discovered by him~~ the form of the function expressing the electron distribution ~~[illegible]~~ over high frequency energies by means of a solution of Boltzmann's kinetic equation. At the same time he took into account elastic and non-elastic electron collisions with the given ~~gaxx~~ gas' particles, proceeding from experimental data for an effective ~~[illegible]~~ cross-section.

Figure 4, putting to use Kihara's formula, shows the coefficient ζ as a function of the relation E/p with different values for $p\lambda$ (where λ = 18.5 cm.).

A comparison of the experimental and the theoretical breakdown intensity is shown by a curve on Fig. 5, from which it may be seen that in the low pressure area, a quantitative divergence takes place as a ~~xxxxx~~ result of the disruption of the diffusion regime ~~disruption~~ ~~[illegible]~~. For the latter it is indispensable that the length of the electron free path be sufficiently small in comparison with the length of the discharge ~~[illegible]~~ interval. A sufficiently close conformity of the theory with the practical results of the experiment shows that basic processes being used for the development of breakdown in the given case appear to be the increase of electrons by way of ionization and their moving away by means of diffusion on the section's wall.

Posin theory [5] worked out for a high frequency pulse discharge within an electronegative gas with a corresponding transition (assuming the pulse duration $\mu \rightarrow \infty$) leads to expressions which could be confronted with the results obtained in the course of a continuous generation.

Posin uses as a breakdown criterion the condition that during the lapse of time of pulse ~~xx~~ transition, the concentration of electrons would increase to a sufficiently great ~~significance~~ value.

The solution or the equation expressing the electron concentration variation during the time which leads to the expression of the effective value of the high frequency field intensity

(6)

constitutes the foundation of the theory. Here $A = 4.10^{-6}$; p = pressure in mm.; B_o = probability of electron K adhesion to molecule C with formation of a negative ion per time unit and with gas pressure of 1 mm.. m, e – circular frequency of the ~~adjacent~~ applied field g – friction factor of electrons with gas molecules.

Figure 6 represents the confrontation of experimental breakdown curves on 1620 and 665 Mc frequencies with formula (6). It shows that: First, with increased pressures there is a relative correspondence between theory and practice, and Second, that with pressure lowering the quantitative dispersion is applicable.

The good agreement of the diffusion theory with experiments [2] and the failure of Posin's theory in case of low pressures, show that in this case the condition of transition to a continuous generation ($\mu \to \infty$) and the non-taking stock of theories of electron decrease at the expense of diffusion does not appear to be substantiated. (or "is without foundation").

It should also be pointed out that ~~on~~ low circular field frequency ω, nearer the collision frequency of the electron with gas molecules [redacted], the relation (6) ~~altogether~~ cannot altogether be ~~confronted~~ reconciled with the experiment because it leads to infinitely large values of breakdown field intensity.

The author expresses his thanks to Prof. H. A. Kaptzov for [redacted] the assistance rendered in carrying out this work.